APPLICATION NOTE

Building Scalable and Interoperable HSR/RSTP Networks Using iS5Com Patented HSR-RSTP Integration Technology

OBJECTIVE

As the reliability requirements within the substation increase, and with the introduction of the IEC-61850 Ethernet-based Process Bus, the need for zero packet loss technology grows. More native HSR IEDs are emerging, and more HSR gateway devices are being introduced to facilitate backward computability with exiting IEDs. With the existing majority of substations running RSTP, the need for ways to integrate RSTP with HSR is becoming more of a requirement than an option. In addition, as the average size of power substations increases over time, and with the number of connected substations also increasing, the need for ways to scale the RSTP network increasingly arises. In light of these challenges, we will address:

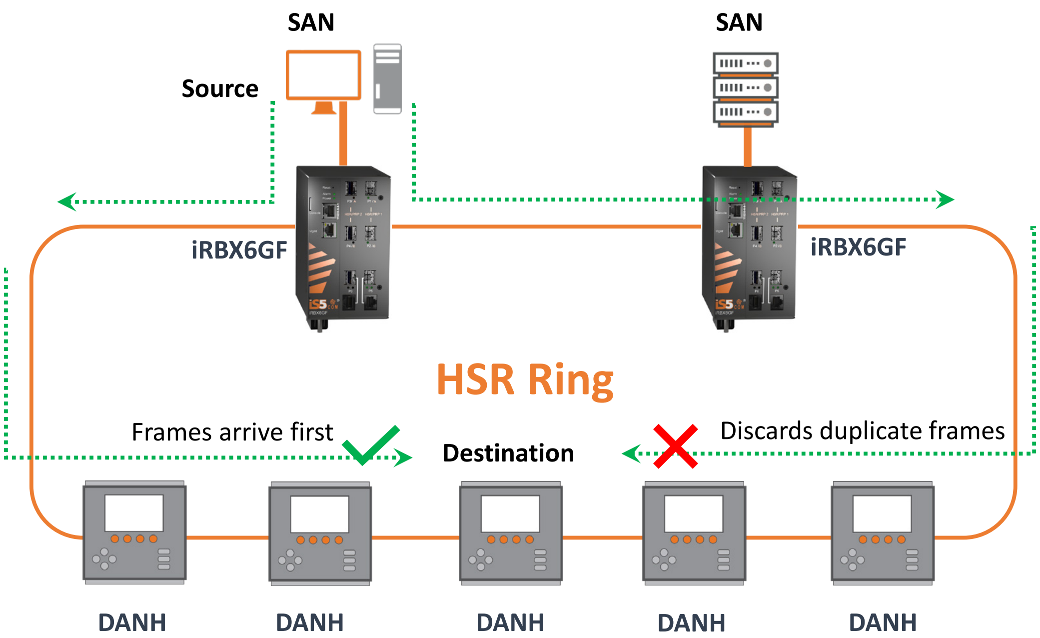
- A quick introduction to the HSR and RSTP protocols at a high level
- The growing need for integrating HSR and RSTP technologies within the substation
- HSR-RSTP integration challenges
- RSTP scalability challenges
- How iS5Com patented HSR-RSTP integration technology addresses both the integration and scalability challenges
- iS5Com product lines integrating the patented iS5 HSR-RSTP technology
- A design case study representing a practical implementation of the solution

HSR AND RSTP PROTOCOLS IN A NUTSHELL

HIGH-AVAILABILITY SEAMLESS REDUNDANCY (HSR) IEC 62439-3

The High-availability Seamless Redundancy (HSR) protocol delivers zero recovery time in case of a network element failure or link failure. The protocol utilizes a ring topology consisting of network nodes and end devices. An HSR network node or a participating end device would have two ports operating in parallel. Utilizing a ring topology, HSR sends messages from the source (publishing device) in duplicates as “A” frame and “B” frame. The frames, in turn, are sent in both directions out of the two ports around the ring. A subscribing device on the HSR ring would accept the first version of the message received and discard the second copy. If a network link fails, at least one of the two messages is guaranteed to arrive at the subscriber device. This architecture creates a “lossless” network that can tolerate a single network device or link failure without losing any frame, seamlessly achieving zero-packet-Loss. IEDs connecting to the HSR ring are either native HSR devices with the HSR capabilities built-in or through an HSR gateway device. The iS5Com iRBX is an example of such an integration gateway.

Figure 1.0



RAPID SPANNING TREE PROTOCOL

Rapid Spanning Tree Protocol (RSTP) (IEEE802.1D 2004) manages redundant paths in Ethernet networks allowing backup links to exist while preventing bridge loops from forming. Bridge loops can lead to broadcast storms, rendering the network unusable. RSTP understands the network topology, determines the most efficient path for traffic, and logically manages port status between forwarding/blocking, eliminating any potential network loops. RSTP uses BPDUs (Bridge Protocol Data Units) that are sent across the network to discover the network topology. Although RSTP facilitates optimal fault re-convergence time usually measured in milliseconds, it does not extend a zero-packet-loss option.

THE GROWING NEED FOR INTEGRATING HSR & RSTP NETWORKS

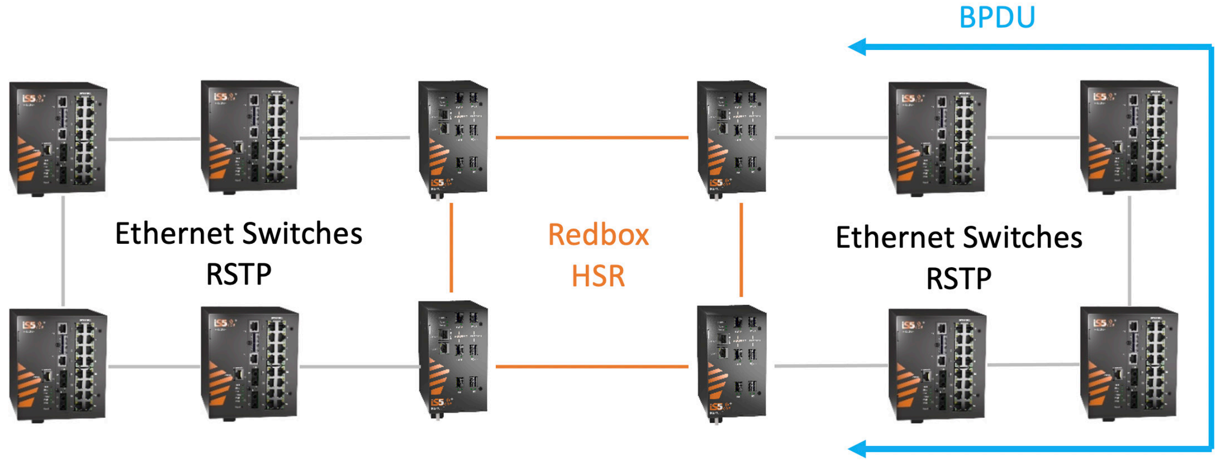
As the need for Zero-Packet-Loss technology in the substation increases, driven by more stringent reliability requirements and the introduction of the IEC-61850 Process Bus, more native HSR IEDs are being connected. Considering that most existing infrastructure IEDs are Ethernet-based, the need to connect HSR and RSTP in a reliable, redundant, fault-tolerant way is becoming a pressing requirement. This requirement is faced with challenges arising from the nature of the protocols and the way they operate. We will explore these challenges in detail in the following section.

HSR – RSTP INTEGRATION CHALLENGES

RSTP is a loop prevention protocol. It works on eliminating network loops to avoid having L2 frames circling a network indefinitely, ultimately deeming the network unusable. It accomplishes its goal by sending BPDUs across the network to discover the network topology and decides if it needs to logically block a network port to prevent the presence of a network loop.

Taking a closer look at a scenario where an RSTP network is dual connected to an HSR setup (dual connectivity is required to satisfy the fault tolerance requirements). Most HSR gateway implementations would carry the data and drop any received BPDUs as the ingress to the HSR ring. Referencing the diagram below, although the HSR ring completes an Ethernet switch loop, and since the BPDUs are not flowing through the HSR ring to the RSTP logic, there is no loop existing, and hence no action is taken by RSTP. Yet, from a data frame standpoint, there is a switch loop, as the HSR ring completes the missing leg in the RSTP ring. This situation would result in a switch loop causing a broadcast storm rendering the entire network unusable.

Figure 2.0

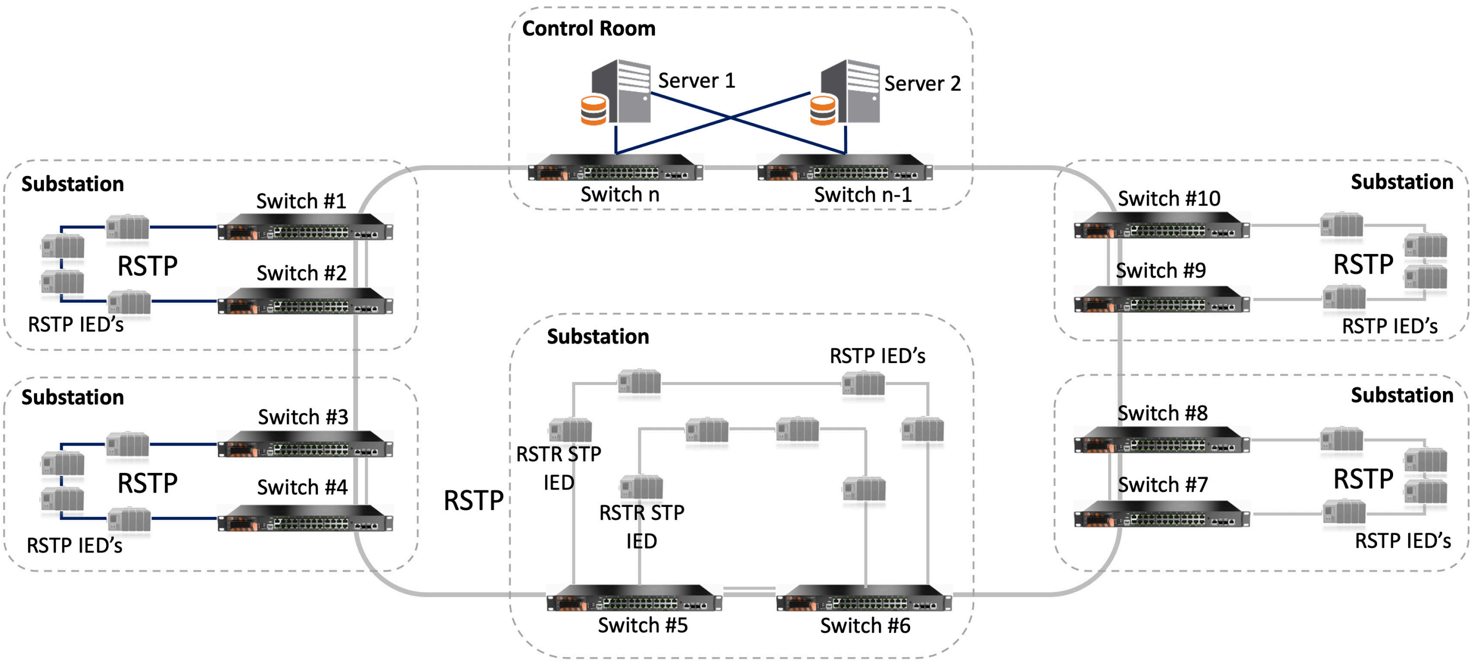


RSTP SCALABILITY CHALLENGES

It comes with the nature of IEC-61850 GOOSE messages as being L2 multicast traffic, the need to extend L2 networks within and across substations. L2 multicast can not be routed, and therefore, for GOOSE control traffic to flow, we need an L2 flat network architecture.

In addition, as existing substations' size grows with some exceeding 800 IEDs at times, and with some GOOSE traffic needed across substations for protection relays to communicate, the need to extend L2 connectivity beyond the substation boundaries increases. Besides being driven by the L2 connectivity requirements, eliminating routing at the control network level is necessary for two more reasons. First, to eliminate a layer of complexity and simplify the network carrying vital protection and control signaling, and second, is the fact that the routing fault re-convergence time is typically measured in seconds and sometimes minutes as opposed to milliseconds in RSTP and L2 switching.

Figure 3.0 - *One RSTP Domain*



Maximum number of SW's Per-Ring is **X**
X = [(38 — **n**)] , **n** is number of switches in main ring
Max Age must be set to **40**

Convergence Time Estimate with Direct Link Failure:
Main Ring: Less than (**n** x 5 msec) + Link failure detection (media dependent)
Relay Ring: Less than (**X** x 5 msec) + Link failure detection (media dependent)

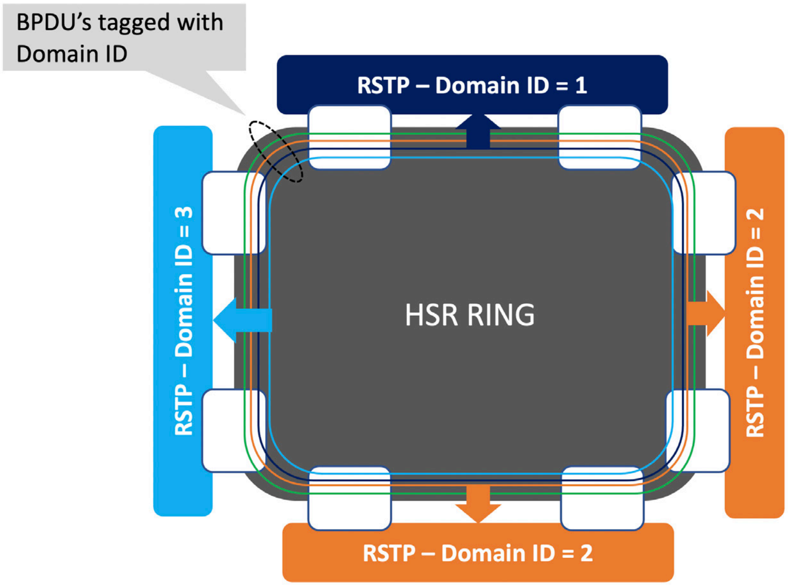
The figure above represents a typical architecture of an L2 protection and control network with multiple substations. The diagram simplifies the setup by assuming one ring of substation and one control room. In real life, the setup would typically include multiple control rooms, at least two, and rings and sub-rings of substations. Within each substation, you would typically find rings and sub-rings of switches and IEDs. As the size of the L2 network grows, we start to run into native RSTP protocol limitations. The first roadblock we hit is the 40 switches hop limit, mandated by the RSTP protocol limitation of BPDU max age value of 40. This limitation is explained in the diagram above, and although the diagram simplified, eliminating rings and subrings of switches, we can still see how much it limits the network size.

The second limitation we run into is the fault re-convergence time for RSTP, which for a simple RSTP ring factors 5ms per switch, excluding a root switch failure condition. For a ring of 20 switches, we anticipate fault re-convergence below 100ms (5 x 20ms). This simple equation dramatically changes as the complexity changes and when a simple ring is replaced with a core ring and multiple levels of sub-rings. As we add switch nodes and complexity to the topology, including rings, sub-rings, and additional redundant links, fault re-convergence time increases dramatically, and the predictability of the re-convergence time starts to become more difficult.

ADDRESSING THE CHALLENGES

Recognizing the integration and scalability challenges, iS5Com has developed its patented HSR-RSTP integration technology with the RSTP domain segmentation feature included. The technology allows HSR and RSTP networks to coexist and integrate with redundant links overcoming interoperability concerns. In addition, it facilitates the ability to segment the RSTP control domain into multiple isolated, smaller, yet flexible architected domains. The segmentation at the RSTP control domain happens while maintaining the L2 connectivity required for GOOSE and other protection and control traffic intact. Let's take a closer look at how the magic works.

Figure 4.0



The diagram above represents an HSR ring as the backbone of a control network constructing a zero-packet-loss robust backbone. Each RSTP zone represents the Ethernet network within a substation/control room, dual-homed to two HSR devices acting as the gateway to the HSR core. iS5Com patented HSR-RSTP technology facilitates carrying RSTP BPDU over the HSR backbone after marking the BPDU packets with an ID representing the RSTP domain it belongs to. RSTP zones with the same domain ID are connected from an RSTP perspective and share the same root bridge.

Each BPDU stream marked with a domain ID is carried separately and independently. This is represented on the diagram with the coloured rings matching the RSTP domain colour they represent. The operator gets to choose whether to put each substation on its own separate RSTP domain, combine multiple small substations into one RSTP domain, or just run a standard flat RSTP domain integrated over an HSR ring. The patented technology facilitates the following:

- Seamless integration of HSR and RSTP networks with redundant connections. This is achieved by carrying RSTP BPDUs over the HSR ring; hence the RSTP protocol sees the HSR ring as an additional data connection as it should and accounts for that in its calculations.
- The ability to segment the RSTP domain, from a control perspective, into smaller domains while maintaining L2 connectivity across all segmented domains. Segmenting the RSTP domain into multiple smaller domains means simpler topology with smaller segments of RSTP, leading to faster fault re-convergence time. In summary, it facilitates:
    - More scalability and ways to overcome the max. hop count limitation
    - Much faster fault re-convergence time

With a single configuration option on the HSR device connecting to the RSTP domain indicating the domain ID, you can have your domains all segmented and ready to go.

Multiple VLANs can run seamlessly over the architecture and be carried over the HSR ring allowing for maintenance, protection, and SCADA to run on separate VLANs. The VLANs can extend over the entire L2 infrastructure facilitating the connectivity required for critical L2 control protocols, yet with segmented RSTP domains, we benefit from the faster re-convergence time. The HSR ring becomes the high availability backbone for the multi-VLAN networks running in smaller segmented RSTP control domains. The setup facilitates a very flexible, low cost and highly available network with optimal fault re-convergence time.

iS5COM PRODUCTS SUPPORTING THE PATENTED TECHNOLOGY

Currently, the iRBX product family integrates an Ethernet switch and an HSR core to fully support the patented HSR-RSTP integration and RSTP domain segmentation features. In the future, the RAPTOR® product line will be able to extend support for the patented feature through an iRBX blade, as a modular option. The RAPTOR platform represents the future of the iS5Com modular product line featuring a modular, high density, and high availability L2/L3 switch platform design.

DESIGN USE-CASE

DESIGN REQUIREMENTS

We are required to redesign a protection & control network for power utility with multiple control rooms and a number of substations varying in size. The substations use IEC-61850 and require a flat L2 architecture that can facilitate L2 GOOSE traffic within and across substations. Due to the large network size, we need to consider the known RSTP protocol limitations on both hop count and increased re-convergence time beyond what is acceptable for protection relays. It is also recognized that some of the new IED's introduced are HSR capable and can benefit from a more reliable zero-packet-loss architecture. Yet, they need to integrate with other Ethernet-based non-HSR capable IED's. Because of its reliability, an HSR core network with zero-packet-loss was considered, but concerns about HSR-RSTP interoperability, especially with redundant links, overweighed the benefits. It's also worth noting that besides the core substation ring, there are sub-rings and, in some cases, additional directly connected fibre links interconnecting rings, providing an additional layer of redundancy.

DESIGN SOLUTION

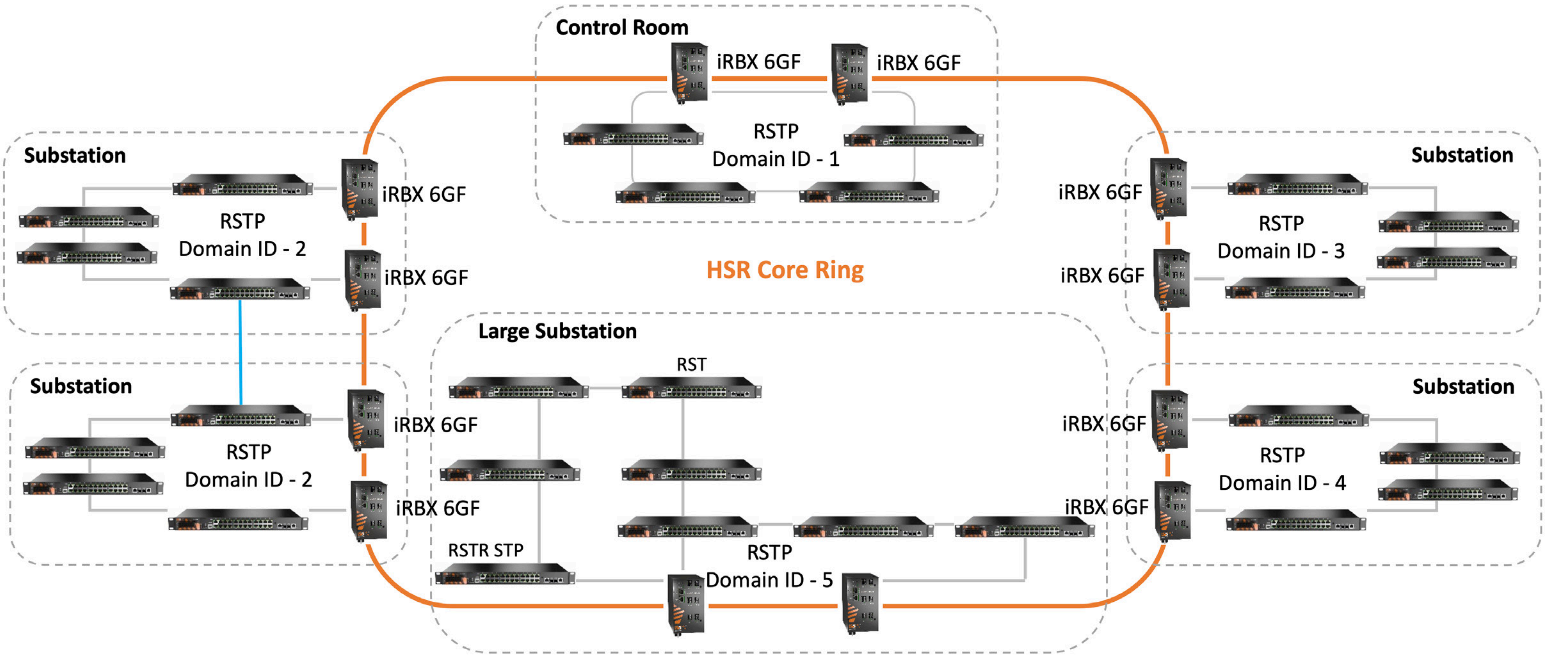
The design requirements are common amongst almost all power utilities; hence it is worth taking a closer look and developing a design template. The idea of having a high availability backbone with Zero-Packet-Loss is quite appealing as well, so let's see how we can overcome the challenges standing in our way to achieving an optimal design.

We will take this design challenge in a two-step approach: first, the core network design, and second, the integration of native HSR IED's within the substation.

1. THE CORE NETWORK DESIGN:

As a solution to the core network, the below diagram is a simplified representation of the switched network. The additional HSR IED integrations within the substation will be addressed later in part two of the design. Also, for the sake of simplicity, we have included one control room and a limited number of substations. Although the number of substations included on the diagram is limited, they construct a representative sample of the ones described in the design requirements section. Small substations with single or double rings and a large substation with some rings/subrings of switches have been included. The diagram also includes an additional fiber link sample, representing an extra available link, added to increase redundancy and availability. You will see this link as the red link on the left side of the diagram.

__Figure 5.0 -__ Multiple RSTP Domains



The solution integrates:

– Designing a high availability HSR core ring featuring a zero-packet-loss architecture

– The use of iS5Com patented HSR-RSTP integration and domain segmentation technology to facilitate:

  o Seamless integration of HSR and RSTP with redundant links (addresses the integration concerns)

  o Segmentation of the RSTP domain into smaller domains in order to address the max. hop count problem, simplify the RSTP topology, and reduce the re-convergence time

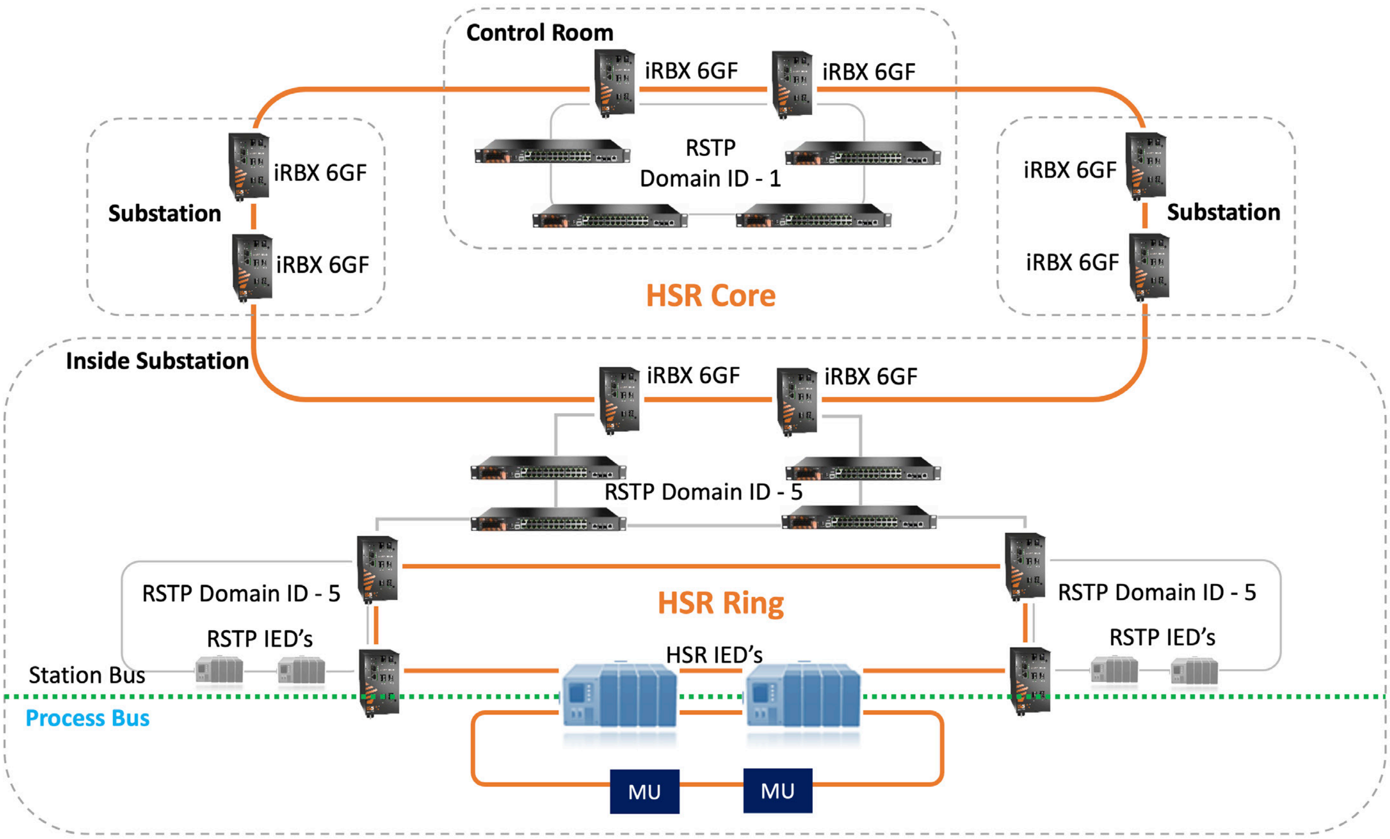
  o Flexibility in RSTP domain segmentation, where, based on the topology and substation size, each substation can be in its own isolated RSTP control domain, or an RSTP domain can be shared between multiple smaller substations without significant impact on re-convergence time.

  o The technology also addresses the concern of the use of HSR alongside the additional direct fibre link outside of the core ring architecture (the red link on the diagram). Keeping the two substations interconnected within the same RSTP domain would seamlessly accommodate the extra redundant link.

2. THE INSIDE-THE-SUBSTATION DESIGN:

Moving on to inside-the-substation-design part, we get to address the challenge of integrating legacy IEDs along sides with new HSR native IEDs. Referencing the diagram below, within the substation, we have two separate buses, the substation bus with all the SCADA and control signaling, and the process bus featuring all the connections to CTs, VTs and MUs. Relays generally sit with one leg on the substation bus and another on the process bus with a network isolation layer in the middle. The network isolation layer is where the control logic was implemented. Gathering data from the process bus, either through legacy connections to CTs and VTs, or in a more modern form over an Ethernet process bus using MUs, relays communicate, receive control and make decisions on the substation bus.

Figure 6.0 - *Inside the Substation*



The diagram features a design example. The same concepts we utilized in integrating HSR and RSTP within the core network apply here too. Utilizing iS5Com patented technology, we can build redundant connections between HSR rings and RSTP rings with no concern in mind. We can also choose to keep everything within the substation bus in the same RSTP domain or segment things further by creating multiple RSTP domains (this can be useful in very large substations).

The diagram shows an RSTP network at the substation level, with an uplink connection to a core HSR backbone through a redundant fault-tolerant setup. The same RSTP substation bus network is connected to an HSR substation bus ring integrating native HSR IEDs and Ethernet IEDs. The combined setup constructs an integrated HSR-RSTP Ethernet-based substation bus.

On the other hand, the process bus features HSR capable IEDs and MUs connected in an HSR ring architecture, forming an Ethernet-based process bus HSR ring.

Combining the two parts of the design, the core network part and the inside-the-substation part, we have an effective design that addresses the initial design challenges and requirements.

ABOUT iS5 COMMUNICATIONS INC.

iS5 Communications Inc. ("iS5Com") is a global provider of integrated services and solutions and manufacturer of intelligent Industrial Ethernet products. Our products are designed to meet the stringent demand requirements of utility sub-stations, roadside transportation, rail, and industrial applications. iS5Com's services and products are key enablers of advanced technology implementation such as the Smart Grid, Intelligent Transportation Systems, Intelligent Oil Field, and Internet of Things. All products have the ability to transmit data efficiently without the loss of any packets under harsh environments and EMI conditions.

iS5 COMMUNICATIONS

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